SCIENCE

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CONTENTS

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CONTINUITY[1]

Natura non vincitur nisi parendo.

FIRST let me lament the catastrophe which has led to my occupying the chair here in this city. Sir William White was a personal friend of many here present, and I would that the citizens of Birmingham could have become acquainted with his attractive personality, and heard at first hand of the strenuous work which he accomplished in carrying out the behests of the empire in the construction of its first line of defence.

Although a British Association address is hardly an annual stocktaking, it would be improper to begin this year of office without referring to three more of our losses:—One that cultured gentleman, amateur of science in the best sense, who was chosen to preside over our jubilee meeting at York thirty-two years ago. Sir John Lubbock, first Baron Avebury, cultivated science in a spirit of pure enjoyment, treating it almost as one of the arts; and he devoted social and political energy to the welfare of the multitude of his fellows less fortunately situated than himself.

Through the untimely death of Sir George Darwin the world has lost a mathematical astronomer whose work on the tides and allied phenomena is a monument of power and achievement. So recently as our visit to South Africa he occupied the presidential chair.

By the third of our major losses, I mean the death of that brilliant mathematician of a neighboring nation who took so com-

[1] Address of the president of the British Association. Read at Birmingham, September 10, 1913.

prehensive and philosophic a grasp of the intricacies of physics, and whose eloquent though sceptical exposition of our laws and processes, and of the modifications entailed in them by recent advances, will be sure to attract still more widespread attention among all to whom the rather abstruse subject-matter is sufficiently familiar. I can not say that I find myself in agreement with all that Henri Poincaré wrote or spoke in the domain of physics, but no physicist can help being interested in his mode of presentation, and I may have occasion to refer, in passing, to some of the topics with which he dealt.

And now, eliminating from our purview, as is always necessary, a great mass of human activity, and limiting ourselves to a scrutiny on the side of pure science alone, let us ask what, in the main, is the characteristic of the promising though perturbing period in which we live. Different persons would give different answers, but the answer I venture to give is—rapid progress, combined with fundamental scepticism.

Rapid progress was not characteristic of the latter half of the nineteenth century—at least not in physics. Fine solid dynamical foundations were laid, and the edifice of knowledge was consolidated; but wholly fresh ground was not being opened up, and totally new buildings were not expected.

In many cases the student was led to believe that the main facts of nature were all known, that the chances of any great discovery being made by experiment were vanishingly small, and that therefore the experimentalist's work consisted in deciding between rival theories, or in finding some small residual effect, which might add a more or less important detail to the theory.—Schuster.

With the realization of predicted ether waves in 1888, the discovery of X-rays in 1895, spontaneous radioactivity in 1896, and the isolation of the electron in 1898, expectation of further achievement became vivid; and novelties, experimental, theoretical and speculative, have been showered upon us ever since this century began. That is why I speak of rapid progress.

Of the progress I shall say little—there must always be some uncertainty as to which particular achievement permanently contributes to it; but I will speak about the fundamental scepticism.

Let me hasten to explain that I do not mean the well-worn and almost antique theme of theological scepticism: that controversy is practically in abeyance just now. At any rate the major conflict is suspended; the forts behind which the enemy has retreated do not invite attack; the territory now occupied by him is little more than his legitimate province. It is the scientific allies, now, who are waging a more or less invigorating conflict among themselves, with philosophers joining in. Meanwhile the ancient foe is biding his time and hoping that from the struggle something will emerge of benefit to himself. Some positions, he feels, were too hastily abandoned and may perhaps be retrieved; or, to put it without metaphor, it seems possible that a few of the things prematurely denied, because asserted on inconclusive evidence, may after all, in some form or other, have really happened. Thus the old theological bitterness is mitigated, and a temporizing policy is either advocated or instinctively adopted.

To illustrate the nature of the fundamental scientific or philosophic controversies to which I do refer, would require almost as many addresses as there are sections of the British Association, or at any rate as many as there are chief cities in Australia; and perhaps my successor in the chair will continue the theme; but, to exhibit my meaning very briefly, I may cite the kind of dominating controversies now extant, employing as far as possible

only a single word in each case so as to emphasize the necessary brevity and insufficiency of the reference.

In physiology the conflict ranges round *vitalism*. (My immediate predecessor dealt with the subject at Dundee.)

In chemistry the debate concerns *atomic structure*. (My penultimate predecessor is well aware of pugnacity in that region.)

In biology the dispute is on the laws of *inheritance*. (My successor is sure to deal with this subject; probably in a way not deficient in liveliness.)

And besides these major controversies, debate is active in other sections:

In education, *curricula* generally are being overhauled or fundamentally criticized, and revolutionary ideas are promulgated concerning the advantages of freedom for infants.

In economic and political science, or sociology, what is there that is not under discussion? Not property alone, nor land alone, but everything,—back to the garden of Eden and the interrelations of men and women.

Lastly, in the vast group of mathematical and physical sciences, "slurred over rather than summed up as Section A," present-day scepticism concerns what, if I had to express it in one word, I should call *continuity*. The full meaning of this term will hardly be intelligible without explanation, and I shall discuss it presently.

Still more fundamental and deep-rooted than any of these sectional debates, however, a critical examination of scientific foundations generally is going on; and a kind of philosophic scepticism is in the ascendant, resulting in a mistrust of purely intellectual processes and in a recognition of the limited scope of science.

For science is undoubtedly an affair of the intellect, it examines everything in the cold light of reason; and that is its strength. It is a commonplace to say that science must have no likes or dislikes, must aim only at truth; or as Bertrand Russell well puts it:

> The kernel of the scientific outlook is the refusal to regard our own desires, tastes and interests as affording a key to the understanding of the world.

This exclusive single-eyed attitude of science is its strength; but, if pressed beyond the positive region of usefulness into a field of dogmatic negation and philosophizing, it becomes also its weakness. For the nature of man is a large thing, and intellect is only a part of it: a recent part too, which therefore necessarily, though not consciously, suffers from some of the defects of newness and crudity, and should refrain from imagining itself the whole—perhaps it is not even the best part—of human nature.

The fact is that some of the best things are, by abstraction, excluded from science, though not from literature and poetry; hence perhaps an ancient mistrust or dislike of science, typified by the Promethean legend. Science is systematized and *metrical* knowledge, and in regions where measurement can not be applied it has small scope; or, as Mr. Balfour said the other day at the opening of a new wing of the National Physical Laboratory:

> Science depends on measurement, and things not measurable are therefore excluded, or tend to be excluded, from its attention. But life and beauty and happiness are not measurable.

And then characteristically he adds:

> If there could be a unit of happiness, politics might begin to be scientific.

Emotion and intuition and instinct are immensely older than science, and in a comprehensive survey of existence they can not be ignored. Scientific men may

rightly neglect them, in order to do their proper work, but philosophers can not.

So philosophers have begun to question some of the larger generalizations of science, and to ask whether in the effort to be universal and comprehensive we have not extended our laboratory inductions too far. The conservation of energy, for instance—is it always and everywhere valid; or may it under some conditions be disobeyed? It would seem as if the second law of thermodynamics must be somewhere disobeyed—at least if the age of the universe is both ways infinite—else the final consummation would have already arrived.

Not by philosophers only, but by scientific men also, ancient postulates are being pulled up by the roots. Physicists and mathematicians are beginning to consider whether the long known and well-established laws of mechanics hold true everywhere and always, or whether the Newtonian scheme must be replaced by something more modern, something to which Newton's laws of motion are but an approximation.

Indeed a whole system of non-Newtonian mechanics has been devised, having as its foundation the recently discovered changes which must occur in bodies moving at speeds nearly comparable with that of light. It turns out in fact that both shape and mass are functions of velocity. As the speed increases the mass increases and the shape is distorted, though under ordinary conditions only to an infinitesimal extent.

So far I agree; I agree with the statement of fact; but I do not consider it so revolutionary as to overturn Newtonian mechanics. After all, a variation of mass is familiar enough, and it would be a great mistake to say that Newton's second law breaks down merely because mass is not constant. A raindrop is an example of variable mass; or the earth may be, by reason of meteoric dust; or the sun, by reason of radio-activity; or a locomotive, by reason of the emission of steam. In fact, variable masses are the commonest, for friction may abrade any moving body to a microscopic extent.

That mass is constant is only an approximation. That mass is equal to ratio of force and acceleration is a definition, and can be absolutely accurate. It holds perfectly even for an electron with a speed near that of light; and it is by means of Newton's second law that the variation of mass with velocity has been experimentally observed and compared with theory.

I urge that we remain with, or go back to, Newton. I see no reason against retaining all Newton's laws, discarding nothing, but supplementing them in the light of further knowledge.

Even the laws of geometry have been overhauled, and Euclidean geometry is seen to be but a special case of more fundamental generalizations. How far they apply to existing space, and how far time is a reality or an illusion, and whether it can in any sense depend on the motion or the position of an observer: all these things in some form or other are discussed.

The conservation of matter also, that main-mast of nineteenth century chemistry, and the existence of the ether of space, that sheet-anchor of nineteenth century physics—do they not sometimes seem to be going by the board?

Professor Schuster, in his American lectures, commented on the modern receptive attitude as follows:-

> The state of plasticity and flux—a healthy state, in my opinion—in which scientific thought of the present day adapts itself to almost any novelty, is illustrated by the complacency with which the most cherished tenets of our fathers are being abandoned. Though it was never an article of orthodox faith that chemical elements were immutable and would not some day be resolved into

simpler constituents, yet the conservation of mass seemed to lie at the very foundation of creation. But nowadays the student finds little to disturb him, perhaps too little, in the idea that mass changes with velocity; and he does not always realize the full meaning of the consequences which are involved.

This readiness to accept and incorporate new facts into the scheme of physics may have led to perhaps an undue amount of scientific scepticism, in order to right the balance.

But a still deeper variety of comprehensive scepticism exists, and it is argued that all our laws of nature, so laboriously ascertained and carefully formulated, are but conventions after all, not truths: that we have no faculty for ascertaining real truth, that our intelligence was not evolved for any such academic purpose; that all we can do is to express things in a form convenient for present purposes and employ that mode of expression as a tentative and pragmatically useful explanation.

Even *explanation*, however, has been discarded as too ambitious by some men of science, who claim only the power to describe. They not only emphasize the *how* rather than the *why*—as is in some sort inevitable, since explanations are never ultimate—but are satisfied with very abstract propositions, and regard mathematical equations as preferable to, because safer than, mechanical analogies or models.

> To use an acute and familiar expression of Gustav Kirchhoff, it is the object of science to *describe* natural phenomena, not to *explain* them. When we have expressed by an equation the correct relationship between different natural phenomena we have gone as far as we safely can, and if we go beyond we are entering on purely speculative ground.

But the modes of statement preferred by those who distrust our power of going correctly into detail are far from satisfactory. Professor Schuster describes and comments on them thus:

> Vagueness, which used to be recognized as our great enemy, is now being enshrined as an idol to be worshipped. We may never know what constitutes atoms, or what is the real structure of the ether; why trouble, therefore, it is said, to find out more about them. Is it not safer, on the contrary, to confine ourselves to a general talk on entropy, luminiferous vectors and undefined symbols expressing vaguely certain physical relationships? What really lies at the bottom of the great fascination which these new doctrines exert on the present generation is sheer cowardice; the fear of having its errors brought home to it. . . .
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> I believe this doctrine to be fatal to a healthy development of science. Granting the impossibility of penetrating beyond the most superficial layers of observed phenomena, I would put the distinction between the two attitudes of mind in this way: One glorifies our ignorance, while the other accepts it as a regrettable necessity.

In further illustration of the modern sceptical attitude, I quote from Poincaré:

> Principles are conventions and definitions in disguise. They are, however, deduced from experimental laws, and these laws have, so to speak, been erected into principles to which our mind attributes an absolute value. . . .
>
> The fundamental propositions of geometry, for instance Euclid's postulate, are only conventions; and it is quite as unreasonable to ask if they are true or false as to ask if the metric system is true or false. Only, these conventions are convenient. . . .
>
> Whether the ether exists or not matters little—let us leave that to the metaphysicians; what is essential for us is that everything happens as if it existed, and that this hypothesis is found to be suitable for the explanation of phenomena. After all, have we any other reason for believing in the existence of material objects? That, too, is only a convenient hypothesis.

As an antidote against over-pressing these utterances I quote from Sir J. Larmor's preface:

> There has been of late a growing trend of opinion, prompted in part by general philosophical views, in the direction that the theoretical constructions of physical science are largely factitious, that instead of presenting a valid image of the relations of things on which further progress can be based, they are still little better than a mirage. . . .

The best method of abating this scepticism is to become acquainted with the real scope and modes of application of conceptions which, in the popular language of superficial exposition—and even in the unguarded and playful paradox of their authors, intended only for the instructed eye —often look bizarre enough.

One thing is very notable, that it is closer and more exact knowledge that has led to the kind of scientific scepticism now referred to; and that the simple laws on which we used to be working were thus simple and discoverable because the full complexity of existence was tempered to our ken by the roughness of our means of observation.

Kepler's laws are not accurately true, and if he had had before him all the data now available he could hardly have discovered them. A planet does not really move in an ellipse but in a kind of hypocycloid, and not accurately in that either.

So it is also with Boyle's law, and the other simple laws in physical chemistry. Even Van der Waals's generalization of Boyle's law is only a further approximation.

In most parts of physics simplicity has sooner or later to give place to complexity: though certainly I urge that the simple laws were true, and are still true, as far as they go, their inaccuracy being only detected by further real discovery. The reason they are departed from becomes known to us; the law is not really disobeyed, but is modified through the action of a known additional cause. Hence it is all in the direction of progress.

It is only fair to quote Poincaré again, now that I am able in the main to agree with him:

Take for instance the laws of reflection. Fresnel established them by a simple and attractive theory which experiment seemed to confirm. Subsequently, more accurate researches have shown that this verification was but approximate; traces of elliptic polarization were detected everywhere. But it is owing to the first approximation that the cause of these anomalies was found, in the existence of a transition layer; and all the essentials of Fresnel's theory have remained. We can not help reflecting that all these relations would never have been noted if there had been doubt in the first place as to the complexity of the objects they connect. Long ago it was said: If Tycho had had instruments ten times as precise, we would never have had a Kepler, or a Newton, or astronomy. It is a misfortune for a science to be born too late, when the means of observation have become too perfect. That is what is happening at this moment with respect to physical chemistry; the founders are hampered in their general grasp by third and fourth decimal places; happily they are men of robust faith. As we get to know the properties of matter better we see that continuity reigns. . . . It would be difficult to justify [the belief in continuity] by apodeictic reasoning, but without [it] all science would be impossible.

Here he touches on my own theme, *continuity;* for, if we had to summarize the main trend of physical controversy at present, I feel inclined to urge that it largely turns on the question as to which way ultimate victory lies in the fight between continuity and discontinuity.

On the surface of nature at first we see discontinuity; objects detached and countable. Then we realize the air and other media, and so emphasize continuity and flowing quantities. Then we detect atoms and numerical properties, and discontinuity once more makes its appearance. Then we invent the ether and are impressed with continuity again. But this is not likely to be the end; and what the ultimate end will be, or whether there is an ultimate end, is a question difficult to answer.

The modern tendency is to emphasize the discontinuous or atomic character of everything. Matter has long been atomic, in the same sense as anthropology is atomic; the unit of matter is the atom, as the unit of humanity is the individual. Whether men or women or children—they can be counted

as so many "souls." And atoms of matter can be counted too.

Certainly however there is an illusion of continuity. We recognize it in the case of water. It appears to be a continuous medium, and yet it is certainly molecular. It is made continuous again, in a sense, by the ether postulated in its pores; for the ether is essentially continuous. Though Osborne Reynolds, it is true, invented a discontinuous or granular ether, on the analogy of the seashore. The sands of the sea, the hairs of the head, the descendants of a patriarch, are typical instances of numerable, or rather of innumerable, things. The difficulty of enumerating them is not that there is nothing to count, but merely that the things to be counted are very numerous. So are the atoms in a drop of water—they outnumber the drops in an Atlantic Ocean—and, during the briefest time of stating their number, fifty millions or so may have evaporated; but they are as easy to count as the grains of sand on a shore.

The process of counting is evidently a process applicable to discontinuities, *i. e.*, to things with natural units; you can count apples and coins, and days and years, and people and atoms. To apply number to a continuum you must first cut it up into artificial units; and you are always left with incommensurable fractions. Thus only is it that you can deal numerically with such continuous phenomena as the warmth of a room, the speed of a bird, the pull of a rope or the strength of a current.

But how, it may be asked, does discontinuity apply to number? The natural numbers, 1, 2, 3, etc., are discontinuous enough, but there are fractions to fill up the interstices; how do we know that they are not really connected by these fractions, and so made continuous again?

(By number I always mean commensurable number; incommensurables are not numbers: they are just what can not be expressed in numbers. The square root of 2 is not a number, though it can be readily indicated by a length. Incommensurables are usual in physics and are frequent in geometry; the conceptions of geometry are essentially continuous. It is clear, as Poincaré says, that "if the points whose coordinates are commensurable were alone regarded as real, the in-circle of a square and the diagonal of the square would not intersect, since the coordinates of the points of intersection are incommensurable.")

I want to explain how commensurable fractions do not connect up numbers, nor remove their discontinuity in the least. The divisions on a foot rule, divided as closely as you please, represent commensurable fractions, but they represent none of the length. No matter how numerous they are, all the length lies between them; the divisions are mere partitions and have consumed none of it; nor do they connect up with each other, they are essentially discontinuous. The interspaces are infinitely more extensive than the barriers which partition them off from one another; they are like a row of compartments with infinitely thin walls. All the incommensurables lie in the interspaces; the compartments are full of them, and they are thus infinitely more numerous than the numerically expressible magnitudes. Take any point of the scale at random, that point will certainly lie in an interspace: it will not lie on a division, for the chances are infinity to 1 against it.

Accordingly incommensurable quantities are the rule in physics. Decimals do not in practise terminate or circulate, in other words vulgar fractions do not accidentally occur in any measurements, for this would mean infinite accuracy. We proceed to as

many places of decimals as correspond to the order of accuracy aimed at.

Whenever, then, a commensurable number is really associated with any natural phenomenon, there is necessarily a noteworthy circumstance involved in the fact, and it means something quite definite and ultimately ascertainable. Every discontinuity that can be detected and counted is an addition to knowledge. It not only means the discovery of natural units instead of being dependent on artificial ones, but it throws light also on the nature of phenomena themselves.

For instance:

The ratio between the velocity of light and the inverted square root of the product of the electric and magnetic constants was discovered by Clerk Maxwell to be 1; and a new volume of physics was by that discovery opened.

Dalton found that chemical combination occurred between quantities of different fractional numbers; and the atomic theory of matter sprang into substantial though at first infantile existence.

The hypothesis of Prout, which in some modified form seems likely to be substantiated, is that all atomic weights are commensurable numbers; in which case there must be a natural fundamental unit underlying, and in definite groups composing, the atoms of every form of matter.

The small number of degrees of freedom of a molecule, and the subdivision of its total energy into equal parts corresponding thereto, is a theme not indeed without difficulty but full of importance. It is responsible for the suggestion that energy too may be atomic!

Mendelejeff's series again, or the detection of a natural grouping of atomic weights in families of seven, is another example of the significance of number.

Electricity was found by Faraday to be numerically connected with quantity of matter; and the atom of electricity began its hesitating but now brilliant career.

Electricity itself—*i. e.*, electric charge—strangely enough has proved itself to be atomic. There is a natural unit of electric charge, as suspected by Faraday and Maxwell and named by Johnstone Stoney. Some of the electron's visible effects were studied by Crookes in a vacuum; and its weighing and measuring by J. J. Thomson were announced to the British Association meeting at Dover in 1899, a fitting prelude to the twentieth century.

An electron is the natural unit of negative electricity, and it may not be long before the natural unit of positive electricity is found too. But concerning the nature of the positive unit there is at present some division into opposite camps. One school prefers to regard the unit of positive electricity as a homogeneous sphere, the size of an atom, in which electrons revolve in simple harmonic orbits and constitute nearly the whole effective mass. Another school, while appreciative of the simplicity and ingenuity and beauty of the details of this conception, and the skill with which it has been worked out, yet thinks the evidence more in favor of a minute central positive nucleus, or nucleus-group, of practically atomic mass; with electrons, larger—*i. e.*, less concentrated—and therefore less massive than itself, revolving round it in astronomical orbits. While from yet another point of view it is insisted that positive and negative electrons can only differ skew-symmetrically, one being like the image of the other in a mirror, and that the mode in which they are grouped to form an atom remains for future discovery. But no one doubts that electricity is ultimately atomic.

Even magnetism has been suspected of being atomic, and its hypothetical unit has

been named in advance the magneton: but I confess that here I have not been shaken out of the conservative view.

We may express all this as an invasion of number into unsuspected regions.

Biology may be said to be becoming atomic. It has long had natural units in the shape of cells and nuclei, and some discontinuity represented by body-boundaries and cell-walls; but now, in its laws of heredity as studied by Mendel, number and discontinuity are strikingly apparent among the reproductive cells, and the varieties of offspring admit of numerical specification and prediction to a surprising extent: while modification by continuous variation, which seemed to be of the essence of Darwinism, gives place to, or at least is accompanied by, mutation, with finite and considerable and in appearance discontinuous change.

So far from nature not making jumps, it becomes doubtful if she does anything else. Her hitherto placid course, more closely examined, seems to look like a kind of steeplechase.

Yet undoubtedly continuity is the backbone of evolution, as taught by all biologists—no artificial boundaries or demarcations between species—a continuous chain of heredity from far below the amœba up to man. Actual continuity of undying germ-plasm, running through all generations, is taught likewise; though a strange discontinuity between this persistent element and its successive accessory body-plasms—a discontinuity which would convert individual organisms into mere temporary accretions or excretions, with no power of influencing or conveying experience to their generating cells—is advocated by one school.

Discontinuity does not fail to exercise fascination even in pure mathematics. Curves are invented which have no tangent or differential coefficient, curves which consist of a succession of dots or of twists; and the theory of commensurable numbers seems to be exerting a dominance over philosophic mathematical thought as well as over physical problems.

And not only these fairly accepted results are prominent, but some more difficult and unexpected theses in the same direction are being propounded, and the atomic character of energy is advocated. We had hoped to be honored by the presence of Professor Planck, whose theory of the *quantum,* or indivisible unit or atom of energy, excites the greatest interest, and by some is thought to hold the field.

Then again radiation is showing signs of becoming atomic or discontinuous. The corpuscular theory of radiation is by no means so dead as in my youth we thought it was. Some radiation is certainly corpuscular, and even the etherial kind shows indications, which may be misleading, that it is spotty, or locally concentrated into points, as if the wave-front consisted of detached specks or patches; or, as J. J. Thomson says, "the wave-front must be more analogous to bright specks on a dark ground than to a uniformly illuminated surface," thus suggesting that the ether may be fibrous in structure, and that a wave runs along lines of electric force, as the genius of Faraday surmised might be possible, in his "Thoughts on Ray Vibrations." Indeed Newton guessed something of the same kind, I fancy, when he superposed ether-pulses on his corpuscles.

Whatever be the truth in this matter, a discussion on radiation, of extreme weight and interest, though likewise of great profundity and technicality, is expected on Friday in Section A. We welcome Professor Lorentz, Dr. Arrhenius, Professor Langevin, Professor Pringsheim and others, some of whom have been specially invited to England because of the impor-

tant contributions which they have made to the subject-matter of this discussion.

Why is so much importance attached to radiation? Because it is the best-known and longest-studied link between matter and ether, and the only property we are acquainted with that affects the unmodified great mass of ether alone. Electricity and magnetism are associated with the modifications or singularities called electrons: most phenomena are connected still more directly with matter. Radiation, however, though excited by an accelerated electron, is subsequently let loose in the ether of space, and travels as a definite thing at a measurable and constant pace—a pace independent of everything so long as the ether is free, unmodified and unloaded by matter. Hence radiation has much to teach us, and we have much to learn concerning its nature.

How far can the analogy of granular, corpuscular, countable, atomic or discontinuous things be pressed? There are those who think it can be pressed very far. But to avoid misunderstanding let me state, for what it may be worth, that I myself am an upholder of *ultimate* continuity, and a fervent believer in the ether of space.

We have already learned something about the ether; and although there may be almost as many varieties of opinion as there are people qualified to form one, in my view we have learned as follows:

The ether is the universal connecting medium which binds the universe together, and makes it a coherent whole instead of a chaotic collection of independent isolated fragments. It is the vehicle of transmission of all manner of force, from gravitation down to cohesion and chemical affinity; it is therefore the storehouse of potential energy.

Matter moves, but ether is strained.

What we call elasticity of matter is only the result of an alteration of configuration due to movement and readjustment of particles, but all the strain and stress are in the ether. The ether itself does not move, that is to say it does not move in the sense of locomotion, though it is probably in a violent state of rotational or turbulent motion in its smallest parts; and to that motion its exceeding rigidity is due.

As to its density, it must be far greater than that of any form of matter, millions of times denser than lead or platinum. Yet matter moves through it with perfect freedom, without any friction or viscosity. There is nothing paradoxical in this: viscosity is not a function of density; the two are not necessarily connected. When a solid moves through an alien fluid it is true that it acquires a spurious or apparent extra inertia from the fluid it displaces; but in the case of matter and ether, not only is even the densest matter excessively porous and discontinuous, with vast interspaces in and among the atoms, but the constitution of matter is such that there appears to be no displacement in the ordinary sense at all; the ether is itself so modified as to *constitute* the matter in some way. Of course that portion moves, its inertia is what we observe, and its amount depends on the potential energy in its associated electric field, but the motion is not like that of a foreign body, it is that of some inherent and merely individualized portion of the stuff itself. Certain it is that the ether exhibits no trace of viscosity.[2]

Matter in motion, ether under strain, constitute the fundamental concrete things we have to do with in physics. The first

[2] For details of my experiment on this subject see *Phil Trans. Roy. Soc.* for 1893 and 1897; or a very abbreviated reference to it, and to the other matters above mentioned, in my small book, "The Ether of Space."

pair represent kinetic energy, the second potential energy; and all the activities of the material universe are represented by alternations from one of these forms to the other.

Whenever this transference and transformation of energy occur, work is done, and some effect is produced, but the energy is never diminished in quantity: it is merely passed on from one body to another, always from ether to matter or *vice versa* —except in the case of radiation, which simulates matter—and from one form to another.

The forms of energy can be classified as either a translation, a rotation or a vibration of pieces of matter of different sizes, from stars and planets down to atoms and electrons; or else an etherial strain which in various different ways is manifested by the behavior of such masses of matter as appeal to our senses.[3]

Some of the facts responsible for the suggestion that energy is atomic seem to me to depend on the discontinuous nature of the structure of a material atom, and on the high velocity of its constituent particles. The apparently discontinuous emission of radiation is, I believe, due to features in the real discontinuity of matter. Disturbances inside an atom appear to be essentially catastrophic; a portion is liable to be ejected with violence. There appears to be a critical velocity below which ejection does not take place; and, when it does, there also occurs a sudden rearrangement of parts which is presumably responsible for some perceptible etherial radiation. Hence it is, I suppose, that radiation comes off in gushes or bursts; and hence it appears to consist of indivisible units. The occasional phenomenon of new stars, as compared with the steady orbital motion of the millions of recognized bodies, may be suggested as an astronomical analogue.

The hypothesis of *quanta* was devised to reconcile the law that the energy of a group of colliding molecules must in the long run be equally shared among all their degrees of freedom, with the observed fact that the energy is really shared into only a small number of equal parts. For if vibration-possibilities have to be taken into account, the number of degrees of molecular freedom must be very large, and energy shared among them ought soon to be all frittered away; whereas it is not. Hence the idea is suggested that minor degrees of freedom are initially excluded from sharing the energy, because they can not be supplied with less than one atom of it.

I should prefer to express the fact by saying that the ordinary encounters of molecules are not of a kind able to excite atomic vibrations, or in any way to disturb the ether. Spectroscopic or luminous vibrations of an atom are excited only by an exceptionally violent kind of collision, which may be spoken of as chemical clash; the ordinary molecular orbital encounters, always going on at the rate of millions a second, are ineffective in that respect, except in the case of phosphorescent or luminescent substances. That common molecular deflexions *are* ineffective is certain, else all the energy would be dissipated or transferred from matter into the ether; and the reasonableness of their radiative inefficiency is not far to seek, when we consider the comparatively leisurely character of molecular movements, at speeds comparable with the velocity of sound. Admittedly, however, the effective rigidity of molecules must be complete, otherwise the sharing of energy must ultimately occur. They do not seem able

[3] See, in the *Philosophical Magazine* for 1879, my article on "A Classification of the Forms of Energy."

to be set vibrating by anything less than a certain minimum stimulus; and that is the basis for the theory of *quanta*.

Quantitative applications of Planck's theory, to elucidate the otherwise shaky stability of the astronomically constituted atom, have been made; and the agreement between results so calculated and those observed, including a determination of series of spectrum lines, is very remarkable. One of the latest contributions to this subject is a paper by Dr. Bohr in the *Philosophical Magazine* for July this year.

To show that I am not exaggerating the modern tendency towards discontinuity, I quote, from M. Poincaré's "Dernières Pensées," a proposition which he announces in italics as representing a form of Professor Planck's view of which he apparently approves:

> A physical system is susceptible of a finite number only of distinct conditions; it jumps from one of these conditions to another without passing through a continuous series of intermediate conditions.

Also this from Sir Joseph Larmor's preface to Poincaré's "Science and Hypothesis":

> Still more recently it has been found that the good Bishop Berkeley's logical jibes against the Newtonian ideas of fluxions and limiting ratios can not be adequately appeased in the rigorous mathematical conscience, until our apparent continuities are resolved mentally into discrete aggregates which we only partially apprehend. The irresistible impulse to atomize everything thus proves to be not merely a disease of the physicist: a deeper origin, in the nature of knowledge itself, is suggested.

One very valid excuse for this prevalent attitude is the astonishing progress that has been made in actually seeing or almost seeing the molecules, and studying their arrangement and distribution.

The laws of gases have been found to apply to emulsions and to fine powders in suspension, of which the Brownian movement has long been known. This movement is caused by the orthodox molecular bombardment, and its average amplitude exactly represents the theoretical mean free path calculated from the "molecular weight" of the relatively gigantic particles. The behavior of these microscopically visible masses corresponds closely and quantitatively with what could be predicted for them as fearfully heavy atoms, on the kinetic theory of gases; they may indeed be said to constitute a gas with a gram-molecule as high as 200,000 tons; and, what is rather important as well as interesting, they tend visibly to verify the law of equipartition of energy even in so extreme a case, when that law is properly stated and applied.

Still more remarkable, the application of X-rays to display the arrangement of molecules in crystals, and ultimately the arrangement of atoms in molecules, as initiated by Professor Laue with Drs. Friedrich and Knipping, and continued by Professor Bragg and his son and by Dr. Tutton, constitute a series of researches of high interest and promise. By this means many of the theoretical anticipations of our countryman, Mr. William Barlow, and—working with him—Professor Pope, as well as of those distinguished crystallographers von Groth and von Fedorow, have been confirmed in a striking way. These brilliant researches, which seem likely to constitute a branch of physics in themselves, and which are being continued by Messrs. Moseley and C. G. Darwin, and by Mr. Keene and others, may be called an apotheosis of the atomic theory of matter.

One other controversial topic I shall touch upon in the domain of physics, though I shall touch upon it lightly, for it is not a matter for easy reference as yet. If the *principle of relativity* in an extreme

sense establishes itself, it seems as if even time would become discontinuous and be supplied in atoms, as money is doled out in pence or centimes instead of continuously—in which case our customary existence will turn out to be no more really continuous than the events on a kinematograph screen—while that great agent of continuity, the ether of space, will be relegated to the museum of historical curiosities.

In that case differential equations will cease to represent the facts of nature, they will have to be replaced by finite differences, and the most fundamental revolution since Newton will be inaugurated.

Now in all the debatable matters of which I have indicated possibilities I want to urge a conservative attitude. I accept the new experimental results on which some of these theories—such as the principle of relativity—are based, and am profoundly interested in them, but I do not feel that they are so revolutionary as their propounders think. I see a way to retain the old and yet embrace the new, and I urge moderation in the uprooting and removal of landmarks.

And of these the chief is continuity. I can not imagine the exertion of mechanical force across empty space, no matter how minute; a continuous medium seems to me essential. I can not admit discontinuity in either space or time, nor can I imagine any sort of experiment which would justify such a hypothesis. For surely we must realize that we know nothing experimental of either space or time, we can not modify them in any way. We make experiments on bodies, and only on bodies, using "body" as an exceedingly general term.

We have no reason to postulate anything but continuity for space and time. We cut them up into conventional units for convenience' sake, and those units we can count; but there is really nothing atomic or countable about the things themselves. We can count the rotations of the earth, or the revolutions of an electron, or the vibrations of a pendulum, or the waves of light. All these are concrete and tractable physical entities; but space and time are ultimate data, abstractions based on experience. We know them through motion, and through motion only, and motion is essentially continuous. We ought clearly to discriminate between things themselves and our mode of measuring them. Our measures and perceptions may be affected by all manner of incidental and trivial causes, and we may get confused or hampered by our own movement; but there need be no such complication in things themselves, any more than a landscape is distorted by looking at it through an irregular window-pane or from a traveling coach. It is an ancient and discarded fable that complications introduced by the motion of an observer are real complications belonging to the outer universe.

Very well, then, what about the ether, is that in the same predicament? Is that an abstraction, or a mere convention, or is it a concrete physical entity on which we can experiment?

Now it has to be freely admitted that it is exceedingly difficult to make experiments on the ether. It does not appeal to sense, and we know no means of getting hold of it. The one thing we know metrical about it is the velocity with which it can transmit transverse waves. That is clear and definite, and thereby to my judgment it proves itself a physical agent; not indeed tangible or sensible, but yet concretely real.

But it does elude our laboratory grasp. If we rapidly move matter through it, hoping to grip it and move it too, we fail: there is no mechanical connection. And even if we experiment on light we fail too. So long as transparent matter is moving

relatively to us, light can be affected inside that matter; but when matter is relatively stationary to matter nothing observable takes place, however fast things may be moving, so long as they move together.

Hence arises the idea that motion with respect to ether is meaningless: and the fact that only relative motion of pieces of matter with respect to each other has so far been observed is the foundation of the principle of relativity. It sounds simple enough as thus stated, but in its developments it is an ingenious and complicated doctrine embodying surprising consequences which have been worked out by Professor Einstein and his disciples with consummate ingenuity.

What have I to urge against it? Well, in the first place, it is only in accordance with common sense that no effect of the first order can be observed without relative motion of matter. An ether-stream through our laboratories is optically and electrically undetectable, at least as regards first-order observation; this is clearly explained for general readers in my book, "The Ether of Space," chapter IV. But the principle of relativity says more than that, it says that no effect of any order of magnitude can ever be observed without the relative motion of matter.

The truth underlying this doctrine is that absolute motion without reference to *anything* is unmeaning. But the narrowing down of "anything" to mean any piece of matter is illegitimate. The nearest approach to absolute motion that we can physically imagine is motion through or with respect to the ether of space. It is natural to assume that the ether is on the whole stationary and to use it as a standard of rest; in that sense motion with reference to it may be called absolute, but in no other sense.

The principle of relativity claims that we can never ascertain such motion: in other words, it practically or pragmatically denies the existence of the ether. Every one of our scientifically observed motions, it says, are of the same nature as our popularly observed ones, viz., motion of pieces of matter relatively to each other; and that is all that we can ever know. Everything goes on—says the principle of relativity—as if the ether did not exist.

Now the facts are that no motion with reference to the ether alone has ever yet been observed: there are always curious compensating effects which just cancel out the movement-terms and destroy or effectively mask any phenomenon that might otherwise be expected. When matter moves past matter observation can be made; but, even so, no consequent locomotion of ether, outside the actually moving particles, can be detected.

(It is sometimes urged that rotation is a kind of absolute motion that can be detected, even in isolation. It can so be detected, as Newton pointed out; but in cases of rotation matter on one side the axis is moving in the opposite direction to matter on the other side of the axis; hence rotation involves relative material motion, and therefore can be observed.)

To detect motion through ether we must use an etherial process. We may use radiation, and try to compare the speeds of light along or across the motion; or we might try to measure the speed, first with the motion and then against it. But how are we to make the comparison? If the time of emission from a distant source is given by a distant clock, that clock must be observed through a telescope, that is, by a beam of light; which is plainly a compensating process. Or the light from a neighboring source can be sent back to us by a distant mirror; when again there will be compensation. Or the starting of light

from a distant terrestrial source may be telegraphed to us, either with a wire or without; but it is the ether that conveys the message in either case, so again there will be compensation. Electricity, magnetism and light are all effects of the ether.

Use cohesion, then; have a rod stretching from one place to another, and measure that. But cohesion is transmitted by the ether too, if, as believed, it is the universal binding medium. Compensation is likely; compensation can, on the electrical theory of matter, be predicted.

Use some action not dependent on ether, then. Very well, where shall we find it?

To illustrate the difficulty I will quote a sentence from Sir Joseph Larmor's paper before the International Congress of Mathematicians at Cambridge last year:

> If it is correct to say with Maxwell that all radiation is an electrodynamic phenomenon, it is equally correct to say with him that all electrodynamic relations between material bodies are established by the operation, on the molecules of those bodies, of fields of force which are propagated in free space as radiation and in accordance with the laws of radiation, from one body to the other.

The fact is we are living in an epoch of some very comprehensive generalizations. The physical discovery of the twentieth century, so far, is the electrical theory of matter. This is the great new theory of our time; it was referred to, in its philosophical aspect, by Mr. Balfour in his presidential address at Cambridge in 1904. We are too near it to be able to contemplate it properly; it has still to establish itself and to develop in detail, but I anticipate that in some form or other it will prove true.[4]

Here is a briefest possible summary of the first chapter (so to speak) of the electrical theory of matter.

1. Atoms of matter are composed of electrons—of positive and negative electric charges.

2. Atoms are bound together into molecules by chemical affinity, which is intense electrical attraction at ultra-minute distances.

3. Molecules are held together by cohesion, which I for one regard as residual or differential chemical affinity over molecular distances.

4. Magnetism is due to the locomotion of electrons. There is no magnetism without an electric current, atomic or otherwise. There is no electric current without a moving electron.

5. Radiation is generated by every accelerated electron, in amount proportional to the square of its acceleration; and there is no other kind of radiation, except indeed a corpuscular kind; but this depends on the velocity of electrons and therefore again can only be generated by their acceleration.

The theory is bound to have curious consequences; and already it has contributed to some of the uprooting and uncertainty that I speak of. For, if it be true, every material interaction will be electrical, *i. e.*, etherial; and hence arises our difficulty. Every kind of force is transmitted by the ether, and hence, so long as all our apparatus is traveling together at one and the same pace, we have no chance of detecting the motion. That is the strength of the principle of relativity. The changes are not zero, but they cancel each other out of observation.

Many forms of statement of the famous Michelson-Morley experiment are misleading. It is said to prove that the time taken by light to go with the ether stream is the same as that taken to go against or across it. It does not show that. What it shows

[4] For a general introductory account of the electrical theory of matter my Romanes lecture for 1903 (Clarendon Press), may be referred to.

is that the time taken by light to travel to and fro on a measured interval fixed on a rigid block of matter is independent of the aspect of that block with respect to any motion of the earth through space. A definite and most interesting result: but it may be, and often is, interpreted loosely and too widely.

It is interpreted too widely, as I think, when Professor Einstein goes on to assume that no non-relative motion of matter can be ever observed even when *light* is brought into consideration. The relation of light to matter is very curious. The wave front of a progressive wave simulates many of the properties of matter. It has energy, it has momentum, it exerts force, it sustains reaction. It has been described as a portion of the mass of a radiating body—which gives it a curiously and unexpectedly corpuscular "feel." But it has a definite velocity. Its velocity in space relative to the ether is an absolute constant independent of the motion of the source. This would not be true for corpuscular light.

Hence I hold that here is something with which our own motion may theoretically be compared; and I predict that our motion through the ether will some day be detected by help of this very fact—by comparing our speed with that of light: though the old astronomical aberration, which seemed to make the comparison easy, failed to do so quite simply, because it is complicated by the necessity of observing the position of a distant source, in relation to which the earth is moving. If the source and observer are moving together there is no possibility of observing aberration. Nevertheless I maintain that when matter is moving near a beam of light we may be able to detect the motion. For the velocity of light in space is no function of the velocity of the source, nor of matter near it; it is quite unaffected by source or receiver. Once launched it travels in its own way. If we are traveling to meet it, it will be arriving at us more quickly; if we travel away from it, it will reach us with some lag. And observation of the acceleration or retardation is made by aid of Jupiter's satellites. We have there the dial of a clock, to or from which we advance or recede periodically. It gains while we approach it, it loses while we recede from it, it keeps right time when we are stationary or only moving across the line of sight.

But then of course it does not matter whether Jupiter is standing still and we are moving, or *vice versa:* it is a case of relative motion of matter again. So it is if we observe a Doppler effect from the right- and left-hand limbs of the rotating sun. True, and if we are to permit no relative motion of matter we must use a terrestrial source, clamped to the earth as our receiver is. And now we shall observe nothing.

But not because there is nothing to observe. Lag must really occur if we are running away from the light, even though the source is running after us at the same pace, unless we make the assumption—true only for corpuscular light—that the velocity of light is not an absolute thing, but is dependent on the speed of the source. With corpuscular light there is nothing to observe; with wave light there is something, but we can not observe it.

But if the whole solar system is moving through the ether I see no reason why the relative ether drift should not be observed by a differential residual effect in connection with Jupiter's satellites or the right and left limbs of the sun. The effect must be too small to observe without extreme precision, but theoretically it ought to be there. Inasmuch, however, as relative motion of matter with respect to the observer

is involved in these effects, it may be held that the detection of a uniform drift of the solar system in this way is not contrary to the principle of relativity. It is contrary to some statements of that principle; and the cogency of those statements breaks down, I think, whenever they include the velocity of light; because there we really have something absolute (in the only sense in which the term can have a physical meaning) with which we can compare our own motions, when we have learned how.

But in ordinary astronomical translation—translation as of the earth in its orbit—all our instruments, all our standards, the whole contents of our laboratory, are moving at the same rate in the same direction; under those conditions we can not expect to observe anything. Clerk Maxwell went so far as to say that if every particle of matter simultaneously received a graduated blow so as to produce a given constant acceleration all in the same direction, we should be unaware of the fact. He did not then know all that we know about radiation. But apart from that, and limiting ourselves to comparatively slow changes of velocity, our standards will inevitably share whatever change occurs. So far as observation goes, everything will be practically as if no change had occurred at all—though that may not be the truth. All that experiment establishes is that there have so far always been compensations; so that the attempt to observe motion through the ether is being given up as hopeless.

Surely, however, the minute and curious compensations can not be accidental, they must be necessary? Yes, they are necessary; and I want to say why. Suppose the case were one of measuring thermal expansion; and suppose everything had the same temperature and the same expansibility; our standards would contract or expand with everything else, and we could observe nothing; but expansion would occur nevertheless. That is obvious, but the following assertion is not so obvious. If everything in the universe had the same temperature, no matter what that temperature was, nothing would be visible at all; the external world so far as vision went, would not appear to exist. Visibility depends on radiation, on differential radiation. We must have differences to appeal to our senses, they are not constructed for uniformity.

It is the extreme omnipresence and uniformity and universal agency of the ether of space that makes it so difficult to observe. To observe anything you must have differences. If all actions at a distance are conducted at the same rate through the ether, the travel of none of them can be observed. Find something not conveyed by the ether and there is a chance. But then every physical action is transmitted by the ether, and in every case by means of its transverse or radiation-like activity.

Except perhaps gravitation. That may give us a clue some day, but at present we have not been able to detect its speed of transmission at all. No plan has been devised for measuring it. Nothing short of the creation or destruction of matter seems likely to serve; creation or destruction of the gravitational unit, whether it be an atom or an electron or whatever it is. Most likely the unit of weight is an electron, just as the unit of mass is.

OLIVER LODGE

(*To be concluded*)

A SUMMARY OF THE WORK OF THE U. S. FISHERIES MARINE BIOLOGICAL STATION AT BEAUFORT, N. C., DURING 1912

THE laboratory of the Bureau of Fisheries at Beaufort, North Carolina, was open as usual during the summer of 1912, and opened about the middle of June, 1913, to investiga-